PHOSPHORUS MANAGEMENT OF DRYLAND WINTER WHEAT

(TRITICUM AESTIVUM L.)

IN WESTERN KANSAS

by

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LITERATURE REVIEW

Phosphorus (P) is an essential plant nutrient in relatively large quantities in plants,thus,proper P management is necessary for optimum crop production. The two major factors involved in P fertilizer management are P rate and method of placement.

Phosphorus Uptake by Winter Wheat

Plants absorb P as $H_2PO_4^{-1}$ and HPO_4^{-2} (Barber,1980). The supply of P to the root is from an available P pool,which represents about 10 t0 30% of the total soil P (Gachon,1978).Three factors affect P supply plant roots ,(1) the amount of soil P (quantity),(2) the concentration of soil solution P (intensity) and (3) movement of P to the roots (diffusion) (Gunary & Sutton,1967). Vetter (1979) showed that the P supply for wheat and barley in soils with different P levels came mainly from the phosphate of the soil,and that no more than 15% of the applied phosphate fertilizer was used the first year of cropping. He concluded that only 1/3 of the phosphate requirement could be supplied from applied phosphate and 2/3 came from the soil re-

serve. Similar results were found by Halvorson et al. (1987) who also demonstrated that P use efficiency was relatively low, only 15 to 20 % of the applied P was used by the first crop. They found also that band placement of P can improve efficiency compared to broadcast. Phosphorus requirement for wheat was estimated to be in the order of 6 to 8 kg P Mg^{-1} (Halvorson, 1987). Phosphorus removed in the grain ranged from 3 to 5 kg P Mg^{-1} of grain.

Absorption rates of P by plant roots was found to follow the Michaelis-Menten kinetics. Barber (1980) proposed the equation:

$$I = I_{max} \frac{C}{K_m + C}$$

Where I_{max} is the maximum rate of P uptake

C is the concentration of P in solution, and

K_m is the Michaelis-Menten constant which is C when $I = 0.5$

Plant age was found to have an effect on the rate of absorption of P, in that the rate of absorption decreases as the plant ages (Jung and Barber, 1975; Edwards and Barber, 1976; and Walker and Barber, 1963). Bowen and Rovira (1977) showed that P absorption rate of wheat roots was higher in the apical 3 cm than in the rest of the root portions.

Many attempts have been made to develop models to

describe the mechanism of P uptake by plant roots (Bouldin,1961;Olsen and Kemper,1968; Brewster et al,1972; Helyar and Munns,1975;and Classen and Barber,1976). All these models estimated and predicted the flux of P to the plant through the root system using different parameters related to soil and plant properties.

Phosphorus uptake by the roots can be calculated in terms of uptake per gram of roots or uptake per unit root length. The latter method is more appropriate because phosphate diffusion to the root is usually the limiting factor in phosphate uptake by lants (Barber, 1977). As the P soil level of the surface soil increases, the relative proportion of P derived from P fertilizer decreases (Fixen and Leikam,1988). With corn (Zea Mays L.), Barber (1977) showed that when the concentration reached 15 M (approximately 0.5 mg/kg),the rate of uptake was near the maximum and increasing the P concentration had very little effect on uptake rate. They concluded that the level of P in soil solution would have had little effect on crop yield if it was increased beyond the concentration needed for maximum uptake.

When fertilizer P is applied to the soil,roots in contact with the fertilizer are supplied with a high level of phosphate,and the remaining roots are supplied with a rate depending on the native soil P. The proportion of roots in contact with the fertilizer P will strongly influence P

uptake. Jungk (1975),demonstrated this effect by splitting the root system, where half the roots received phosphate and the other half did not. He found that for the first one or two days after splitting the root system,phosphate uptake per plant was proportional to the amount of root system supplied with phosphate.

The volume of soil fertilized also influences the degree of root contact with the fertilized soil. Yao et al (1986) showed that if a broadcast plow application fertilized 100%, a 75 cm spaced band application fertilized only about 1% of the soil volume. They concluded that actually more than 1% of the root system was affected by the band due to the proliferation of the roots in the band. They proposed an equation relating the fraction of soil fertilized (X) to the fraction of root system in the band (Y): $Y = X^{0.5}$. The presence of nitrogen (N) further increased the root proliferation in the band (Duncan and Ohlrogge,1958).

Another significant aspect of the soil volume fertilized was recently demonstrated by Nebraska researchers. These data showed that under normal operating condition,pumps commonly used for banding produced a series of droplets rather than continuous bands once a critical minimum application rate was reached (Eghball and Sander,1986). The speed of the application and the diameter of the fertilizer delivery tube also affects this relationship (Fixen and Leikam,1988).

Since fertilizer P is relatively immobile in soils,the location of fertilizer placement becomes very important. The objective is to place the fertilizer where roots are most concentrated and active. In an experiment conducted in central South Dakota ,it was shown that when P was broadcast and only shallowly incorporated with sweeps prior to seeding, wheat yields were still increasing at the highest rate of applied P (224 kg P_2O_5/ha)(Fixen and Leikam,1988). Fertilizer P efficiency had obviously been affected.

The rate at which P fertilizer is applied to the soil is the most important single factor affecting the P avail ability to plant. It is obvious that we apply fertilizer to the soil to make P more available to the plant. Fixen and Leikam (1988) reported that the first increment of fertilizer had only minor impact on P in solution because of the absorption and precipitation. As the application rate increased, more P remained in soil solution for uptake by roots.

Placement method can be classified under two types: broadcast and band methods. The most common method is to broadcast a fluid or dry P material on the soil surface with incorporation by disking or other tillage operations. Broadcasting places P in the tilled part of the soil with uniformity dependent on the method of tillage. Phosphorus incorporation is needed to place the P deeper in the root

zone,to increase the probability of fertilizer contact. This is particularly important in years or areas with low rainfall where the crop depends more on moisture from lower soil depth. The tillage implement will have an important bearing on the depth of P incorporation. A oneway or moldboard plow mixes the P to the depth of tillage. Disking incorporates fertilizer to approximately one-half the tillage depth. A chisel plow or field cultivator incorporates less than a disk since soil is lifted rather than mixed thoroughly to the depth of tillage (Kissel and Whitney,1979).

The second type is band placement. Various labels have been used to describe fertilizer placement: "deep placement", "deep banding", "knifing", "preplant banding", "double shooting", and root zone banding". In all these placement methods,nutrients are concentrated close to or in contact with the seed (Murphy,1983). "Dual application" is a term used in recent years to refer to preplant application of ammonia and liquid mixed fertilizers. Usually fertilizers with low N to P ratios such as 18-46-0 (solid) and 10-34-0 (liquid) are band applied. These materials are used to avoid high rates of N or potash with the seed yet provide adequate amounts of N and P early in the plant growing cycle (Kissel and Whitney,1979).

In recent years most of the work done on P management was done on winter wheat specially in the Great Plain re-

gion. McConnell,et al,(1986), studied different methods of P application on winter wheat over nine locations in eastern,central,and southwestern Nebraska. Grain yield was increased by applied P at all locations. Phosphorus efficiency was increased as measured by grain yield;however,the effect of application depth varied depending on location. They also found that,although P knifed prior to planting was a good method of application,it was not better than seed applied P. Both the test weight and heads ha^{-1} increased linearly with increasing P rate.

Another aspect of the efficiency of P is the effect of N associated with P application. In a 3-year Colorado study, subsurface and surface banded P and N fertilizers were superior to surface broadcast in dryland winter wheat,(Wood,et al,1988). surface banding of P and N fertilizer over the seed row after row closure was equal to banding below the seed. They concluded that dryland winter wheat producers could expect maximum fertilizer efficiency and yield response with dribble over the row placement. Equal effectiveness of the surface band method was largely due to soil and fertilizer band configuration resulting from the use of "hoe" type planter/fertilizer applicators. Maxwell et al,(1984),found that application of deep placed preplant bands of N and P at 38 and 25 cm spacing might be adequate for production of winter wheat in soils testing low

in available P. While not significantly superior to the 50 cm spacing in terms of grain yields,38 and 25 cm spacing did give more uniform plant growth and dry matter production early in the growing season . They concluded that the most desirable band spacing might depend on the row spacing of the wheat as well as the band spacing since both affect the degree of shielding of some wheat rows by others. Sleight,et al,(1984) worked on oats (Avena sativa L) in a greenhouse study to determine why band applied P was more effective than broadcast application at equal P rates. In a calcareous, high P fixing,silt loam soil,they found that increasing root-fertilizer contact was more important than reducing soil-fertilizer contact for effective utilization of the fertilizer during the first weeks of growth. They concluded that if all of the fertilizer was to be placed close to the seed,the application method for most efficient utilization of fertilizer P during early growth required thorough mixing with the soil.

In Kansas studies,dryland grain sorghum (Sorghum bicolor L.) response to P fertilizer rate and placement depended primarily on the availability of native P and residual P from previous P fertilization (Havlin and Lamond,1988). They concluded that the crop response to residual P reserves could be important in years with adequate rainfall,P efficiency was increased by band application on low P soils relative to broadcast P. In addition banded P was more

efficient in producing dry matter than broadcast P even in dry years. They suggested that banded P could advance maturity,thus avoiding the time of greatest probability of drought stress.

In another study conducted in a tropical area (Brazil) with tropical crops: coffee (coffea arabica L.),Malvolta et al (1977) found that under field conditions with coffee and passion fruit plant,within soil application;the placement of fertilizer in circular strip (band) around the trees had provided for a better uptake than other types of distribution,such as circular furrows and holes .

Yield Response to P Fertilization

The evaluation and quantification of yield response to a fertilizer is the main objective of most fertility research. The first step is usually to assess the nutrient level in the soil measured by soil test,and then to relate this to a production parameter (usually the yield) as influenced by different fertilizer rates. Researchers over the years presented this relationship under different forms. In 1913 Mitsherlich proposed an equation relating yield (Y) to an applied nutrient (b). The equation was gradually modified and improved by researchers. The Bray modified form of this equation is:

$$(A-y) = \log A - c_1 b \ ,$$

where A is the maximum yield obtained when all the factors are adequate. y is the yield at a given level of fertilizer (b),and c_1 is a constant. It is important that the mathematical function used represents the biological system over a wide range of nutrient levels (Melsted and Peck,1979). The objective of soil testing is to be able to predict the nutrient response independently of other factors such as climate,soil productivity potential,and management practices. The choice of a particular response model is determined by the goodness of fit of the model (Cochrane,1988). Quadratic and exponential functions are the most frequently used. The quadratic function is widely adopted and was reviewed and refined by Heady (1960), FAO (1966),and Cooke (1975). This equation relates yield (y) to the available soil P (x): $y = a + bx + cx^2$

Another version is the square root form: $y = a + bx^{1/2} + cx$. The quadratic equation has the advantage of reaching a maximum with increasing the rate of the nutrient but it usually fails to represent the actual maximum and to predict the toxic level of a nutrient. The exponential function is: $Y = A[1-B*\exp(-CX)]$,where A is the maximum yield,(Y) is the yield at a given level of available P (X),B is the maximum yield expressed as a fraction of A,and C is a constant (Ozanne,1980). This equation has the advantage of approximating biological growth,but it has the disadvantage of never reaching an absolute maximum. Cochrane

(1988) suggested that for area with insufficient data or where a new crop is introduced ,an alternative model might be considered ,an example of such model is a sigmoid function: $\ln(Y-Y_m) = kF + C$,where Y is the yield,Y_m the maximum yield, F is the fertilizer applied from an inflection point in the sigmoid curve.

Bray (1948) introduced the notion of percent yield ,and it was used later by Cate and Nelson (1965) to define the critical level of a nutrient (P and K) for wheat. The critical level of a nutrient can be defined as (1) the minimum concentration required for maximum growth (Tyner,1947),(2) a concentration that correspond to 95% of maximum productivity (Bennet et al.1953),or (3) the concentration of nutrients in plant below which the yield begins to drop in comparison with plants having higher concentrations (Davidescu,1982). The economic concept was also introduced and it was defined as the level at which the nutrient should be supplied to give the optimum yield and above which fertilizer application is not profitable (Dumenil,1961). The optimum rate of application would be expected to be lower as soil test P increases. Fertilization is not always recommended if the soil test exceeds the critical level,even though many researchers found it still profitable to continue to fertilize even with soil P test in the high range.

OBJECTIVES

Studies were initiated to achieve the following objectives:

1. Quantify optimum P rate fertilization of dryland wheat throughout western Kansas.
2. Establish the optimum fertilizer P placement method for maximum wheat yields at several locations.
3. Evaluate the influence of soil extractable P on grain yield response to P rate and method of placement.
4. Determine the relationship between sampling depth and fertilizer P requirement for winter wheat.
5. Evaluate soil test calibrations for Bray-1, Mehlich,and Olsen extractable P soil tests.

MATERIALS AND METHODS

Phosphorus rate and placement experiments were conducted in western Kansas between 1986 and 1988. A description of the locations is in Table 1. Phosphorus rate studies were conducted at all locations;however, P placement studies were only conducted at Ford,Kearny,Gray,Trego,and Greeley Co. locations. Phosphorus rates (0,7,15,22,29,and 37 kg P/ha were evaluated in a randomized complete block design with four replications. Phosphorus treatments were banded 5 cm below the seed at planting time.

In the placement study four methods of placement were evaluated: broadcast (BC),knifed or deep band (KN) (5 cm below the seed),surface banded or dribbled over the row (DR),and seed placed or with the seed (SD). Four rates of P (0, 7, 22,and 37 kg P/ha) were applied with each placement method . A split-plot design was used with P rate and P placement as the main plots and subplots respectively.

Ammonium polyphosphate (10-34-0) was used as the P source, and urea ammonium nitrate (28-0-0) was added to the P rate treatments in variable amounts to maintain a constant N rate of 23.5 kg N/ha (quantity of N in 37 kg/ha P). Approximately 67 kg N/ha as ammonium nitrate (34-0-0) was broadcast in the spring to all rate and placement studies. Plots were 2m x 10m. Tam 107 wheat was planted at all locations at 67 kg/ha in 30 cm rows. Studies were planted using

a 6-row hoe drill designed to apply all P treatments at planting. 2,4-dichlorophenoxy acetic acid (2,4-D/Banvel) was spring applied at each location to control broadleaf weeds.

The first year,locations were planted from 18 to 25 Sep. 1986, and harvested from 24 June to 9 July. 1987. The second year,planting was from 12 to 18 Sep. 1987,and harvesting from 26 June to 2 July. 1988. Plots were harvested by either 2-row binder (middle 2-rows) and stationary thresher or by a 4-row plot combine. Ten m of row were harvested at all locations.

Test weight and moisture content were measured and grain yields were corrected to 125 g/kg moisture concentration. A grain subsample was taken from each treatment and ground to 1-mm with a UDY mill. Grain N and P were determined by digesting 0.25 g of grain in H_2O/H_2SO_4 (Linder and Harley,1942) and analyzing the digest on a LaChat flow injection autoanalyzer (QiuickChem systems).

Prior to planting,soils in the rate studies were sampled in 0 to 7.5, 0 to 15, 0 to 22.5, 0 to 30, 7.5 to 15, 15 to 22.5,and 22.5 to 30 cm increments. Samples were analyzed at the 'ServiTech' laboratory for Mehlich(II) (Nelson et al,1953), sodium bicarbonate (Olsen,1954) ,and Bray-1 (Bray and Kurtz,1945) phosphorus. Analysis of variance (ANOVA), General linear model (GLM),and Non linear regression (NLIN) procedures in SAS were used to analyze the data (SAS,1982).

Table 1. Selected soil properties from the experiment locations.

County	Soil classification	pH	Phosphorus		
			Bray-1	Olsen	Mehlich
			-------	mg/kg	------
Trego1	Unclassified	8.0	7.5	6.0	8.0
Kearny	Ulysses silt Aridic Haplustoll	7.9	10.5	8.0	10.0
Gove	Ulysses silt Aridic Haplustoll	8.1	8.0	6.0	9.0
Scott	Ulysses silt Aridic Haplustoll	8.1	10.0	7.0	10.0
Ford	Harney silt Typic Argiustoll	7.9	6.0	5.0	6.5
Gray	Richfield silt Typic Argiustoll	7.2	11.0	9.0	12.0
Greeley	Ulysses silt Aridic Haplustoll	7.8	19.0	15.0	21.0
Trego2	Unclassified	6.8	17.0	10.0	18.0

† Soil tests are from 0-15 cm sample depth.

RESULTS AND DISCUSSION

P Rate Study

In both 1986-87 and 1987-88 experiments,wheat grain yield response to P fertilizer was significant at all locations (Table 2). In a low P soil (Ford Co.),only 25% of the yield response was produced with the first P rate increment (7 kg P/ha). In contrast,the first increment produced around 90% of the yield increase in a medium P soil (Kearny Co.). In the 1986-87 studies,significant yield responses to 15, 22, 7, 22,and 15 kg P/ha were obtained at Ford,Trego,Kearny,Gove,and Scott Co. locations, respectively.

In the 1987-88 experiments,significant yield responses were obtained with 7, 15,and 15 kg P/ha in Gray, Trego, and Greeley Co. locations,respectively. The yield level was higher in Gray Co.,exceeding 3.5 Mg/ha compared to only 2.3 and 2.5 Mg/ha, respectively in Trego and Greeley Co.,and was partly due to the relatively favorable climatic conditions in Gray Co. especially during grain filling stage. A lack of moisture was reported in the two other locations during the tiller and joint stage of growth.

In general,yield response was related to soil P test level (Fig.1);decreasing soil P level resulted in higher probability of fertilizer P response and a higher P rate requirement for maximum yield.

Grain N content significantly increased with increas

ing P application only at the Ford Co. location (Table 3). Grain N concentration reached a maximum of 2.0% (11.4% protein content) with 15 kg P/ha application. In 1987-88 experiments an average of 1.75,1.83,and 1.85% N averaged over all P rate treatments was found respectively in Gray,Trego,and Greeley Co. locations. The lower grain yield in Trego and Greeley produced a higher grain N content as compared with the Gray Co. location which produced a higher grain yield but lower N content. This could be explained by the dilution effect. In years of normal rainfall,grain yield increases greater than N accumulation resulting in lower grain protein compared to dry years.

In all locations total N uptake was lower in the check treatment compared to fertilizer P treatments and increased with increasing P rate (Table 4). In all locations N use efficiency increased with P rate,except at the Kearny Co. location ,this was probably related to the relative high soil P content (14 mg/kg) (Table 5).

Significant P rate effect on grain P concentration was observed at Ford and Trego Co.(Table 6). At these two locations grain P concentration increased with increasing P rate. At the Gove Co. location,the higher grain P content was associated with a lower total grain yield . The same trend was found in Trego and Greeley Co.locations. At all locations total P uptake increased with P rate (Table 7).

Phosphorus use efficiency was relatively low ranging from 7% in Trego Co.to 20% in Ford Co.(Table 8). Phosphorus use efficiency was inversely related to the soil P. In general, P use efficiency was higher in soils testing low in extractable P,compared to soils with high soil P test, with the first P rate increment. It seemed that a relatively constant total amount of P (7 to 12 kg P/ha on the average) was removed by wheat grain in which a lower grain yield was offset by a higher total P content (dilution effect).

Rate and Placement Study

Averaged over P placement,grain yield responses to P placement methods were highly significant in all locations (Table 9). The first P increment (7 kg P/ha) produced 57% and 81% of the total yield response at the Ford Co.location (7 mg/kg Bray-1 P) and at Kearny Co.location (14 mg/kg Bray-1 P),respectively. The single degree of freedom comparison between check vs fertilized treatments was highly significant in all locations. Averaged over P rates,the grain yield increase to P fertilizer was 536, 680, 457, 881, and 443 kg/ha grain yield at the Ford, Kearny, Gray, Greeley,and Trego Co.locations,respectively. The low yields at the Ford and Trego Co.sites were due to the relatively unfavorable climatic conditions during the growing season.

When averaged over P rates,no significant differences were found between the three banded treatments (KN,DR,and

SD);however,a significant difference existed between broadcast and the mean banded treatments (Table 9). Averaged over placement method,banded P produced an average 182, 239, and 295 kg/ha more yield than broadcast P at the Ford, Greeley, and Trego Co. locations,respectively. In Kearny Co. site,P placement response was not observed due to the medium soil P level. At the Gray Co. location, no differences between broadcast and banded application were observed and might be explained by the relatively favorable climatic conditions. Broadcast P could be as effective as banded P since plant roots can develop favorably under good moisture supply,thus,exploring more broadcasted P (Fixen and Leikam,1988).

Response to P placement method was related to soil P test level. In soils testing low in extractable P,a large difference in response between broadcast and banded application was observed (Fig.2a);however, the difference decreased as the soil P level increased. With soil testing greater than 12 mg/kg Bray-1 P ,broadcast P could be as effective as band application (Fig. 2b). A critical level of 10 to 12 mg/kg was determined using the Cate Nelson graphics method (Nelson and Anderson,1979). The effect of placement method was function of P rate,banded application would perform better with lower P rates (Fig.3,Appendix Table 1).

In general,it was shown here that band application improved grain yield compared with broadcast application,and

that different band applications performed equally. The response to application method was a function of soil test P and growing conditions. The lower the soil test P level the higher the probability that banded application will perform better than broadcast. Broadcast is expected to be as effective as banded P for soil P tests greater than 10 to 12 mg/kg Bray-1 P.

Soil P test calibration

In addition to the 1986-88 data,we included studies conducted in western Kansas and eastern Colorado in 1984-86 (Tables 10,11). In Figure 4 ,the yield response data for 22 locations (1985-88) were expressed as 'percent yield' defined as the ratio of grain yield at '0' level of applied P to the grain yield where a statistically significant response to fertilizer P was observed (or maximum yield) multiplied by 100 . In general,the percent yield increased as the Bray-1 soil P test increased to the critical soil test P level. The critical level was determined using the Cate-Nelson graphical method. Results showed that yield responses to P fertilizer were probable when extractable phosphorus were below 21, 13, and 23 mg/kg for the Bray-1,Olsen,and Mehlich soil P tests,respectively (Fig. 4,5,6).

The data were fit to the exponential model used by KSU Soil Testing Lab for P recommendation for winter wheat in

western Kansas. The model expresses the recommended P rate (Y) in lb P_2O_5/a as function of soil P (X) in mg/kg. The equation currently used is:

$$Y = \exp[A + B(X) + C(X^2)] \qquad (1)$$

where, A = 4.0880, B = -0.02803, and C = -0.0007102

A similar equation was used with the 1985-88 data (Fig. 7). The new parameters are:

A = 4.5597, B = -0.00510, and C = -0.002979

Similar equations were developed for the Olsen and Mehlich soil tests (Fig. 8,9).

Relative to the 1985-88 data the model currently used by KSU Soil Testing Lab underestimated fertilizer P recommendation, especially in soils testing low in extractable P. From the calibration curves (Fig. 7,8,9), based on a 0 to 15 cm sampling depth for the three soil tests, P recommendations are shown in (Table 12).

The depth of soil sampling strongly affected extractable P level (Fig. 10,11,12). Increasing sampling depth decreased Bray, Olsen, and Mehlich soil test P level. The extractable P levels for each soil test from the 1986-88 locations were correlated with each other and the following relationships were found:

$$\text{Mehlich} = 0.0004 + 1.0819\ (\text{Bray}) \quad R^2 = 0.87 \qquad (2)$$

$$\text{Olsen} = 1.8257 + 0.5615\ (\text{Bray}) \quad R^2 = 0.85$$

$$\text{Olsen} = 2.5415 + 0.4056\ (\text{Mehlich}) \quad R^2 = 0.84$$

The extractable P levels at the 0 to 22.5 cm (D2) and

0 to 30 cm (D3) depths were correlated with the 0 to 15 cm (D1) depth to determine the effect of sampling depth on P recommendation (Table 14), the following relationships were obtained:

Bray-1 test

$$D2 = -1.187 + 0.979(D1) \qquad R^2 = 0.84$$

$$D3 = -1.901 + 0.923(D1) \qquad R^2 = 0.66$$

Mehlich test

$$D2 = -0.217 + 0.817\ (D1) \qquad R^2 = 0.91$$

$$D3 = 0.845 + 0.642\ (D1) \qquad R^2 = 0.78$$

Olsen test

$$D2 = 1.317 + 0.661\ (D1) \qquad R^2 = 0.78$$

$$D3 = 3.170 + 0.340\ (D1) \qquad R^2 = 0.29$$

Using equation (2) for each test,soil P test ranges as function of sampling depth were determined for Mehlich and Olsen tests (Table 14). In general,for all tests soil P test range for a given P rate recommendation decreased with increasing sampling depth. For Bray-1 test,the lower soil P test range,corresponding for the maximum P recommendation,decreased from 5 mg/kg at 15 cm to 3 mg/kg at 30 cm depth. Similar decreases were observed for the Olsen and Mehlich soil tests. The critical value,beyond which no P response is expected also decreased with sampling depth. Compared to the 0-15 cm sampling depth critical values for the 0-30 cm sampling depth decreased from 22 to 18, 14 to

9,and 24 to 17 mg/kg for the Bray-1, Olsen,and Mehlich,respectively.

CONCLUSIONS

Grain yield response to P fertilization was inversely related to soil P test level. The lower the extractable soil P the higher the probability of a P response.

Critical levels of 21, 23, and 13 mg/kg were determined for Bray-1, Mehlich, and Olsen P tests,respectively. No P response is expected beyond these levels. Band application of P improved grain yield compared with broadcast;however,the response to application method was a function of soil test P. The lower the soil test P the higher the probability that band application will perform better than broadcast. Broadcast is expected to be as effective as banded P for soil P tests greater than 10 to 12 mg/kg Bray-1 P. Sampling depth strongly influenced P requirement for wheat. For the same optimum fertilizer rate,lower soil P test categories were needed as soil sampling depth increased.

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Table 2. Effect of P rate on winter wheat grain yield in western Kansas in 1986-88.

	Locations								
P Rate	Ford[1]	Tregol	Kearny[1]	Gove[1]	Scott[1]	Greeley1[1]	Gray[2]	Trego2[2]	Greeley
kg P/ha					Mg/ha				
0	1.78	2.93	2.97	1.96	2.21	2.15	3.10	1.59	1.78
7	2.12	3.20	3.50	2.11	2.46	2.74	3.57	1.93	2.01
15	2.53	3.26	3.55	2.27	2.81	2.74	3.80	2.05	2.30
22	2.61	3.53	3.40	2.50	2.68	2.70	3.58	2.19	2.11
29	3.11	3.26	3.57	2.42	2.91	2.94	3.75	2.34	2.14
37	2.99	3.46	3.37	2.23	2.74	2.72	3.57	2.23	2.50
LSD(5%)	0.66	0.39	0.45	0.36	0.41	0.43	0.43	0.37	0.42
(10%)	0.52	0.32	0.37	0.29	0.33	0.35	0.33	0.25	0.34
CV(%)	17.2	7.8	8.8	10.4	10.2	8.3	4.9	9.8	12.9

1 Locations used in developing figures 10 to 12.
2 1987-88 Locations.

Table 3. Effect of P rate on winter wheat grain N content in western Kansas in 1986-88.

	Locations							
P Rate	Ford	Tregol	Kearny	Gove	Scott	Gray[2]	Trego2[2]	Greeley[2]
kg P/ha	g/kg							
0	18.6	17.0	14.5	13.4	15.0	16.7	17.8	18.3
7	18.9	16.6	13.9	15.0	14.9	18.4	18.1	18.3
15	20.4	16.7	13.5	13.8	16.2	17.1	18.6	18.8
22	19.3	15.2	14.1	14.2	15.6	17.3	18.3	18.6
29	19.9	17.1	12.4	13.8	15.7	18.0	18.0	18.7
37	20.7	15.1	13.5	15.1	15.1	17.7	19.0	18.0
LSD(0.05)	1.7	NS	NS	NS	NS	NS	NS	NS
(0.10)	1.1	1.7	1.7	0.9	NS	1.2	1.0	NS
CV(%)								

2 1987-88 locations

Table 4. Effect of P rate on winter wheat grain N Uptake in western Kansas in 1986-88.

P Rate	Ford	Tregol	Kearny	Gove	Scott	Gray[2]	Trego2[2]	Greeley[2]
	Locations							
kg P/ha	kg/ha							
0	33.1	49.8	43.2	26.2	33.1	51.7	28.3	32.7
7	40.2	53.3	48.8	31.7	36.6	65.7	35.0	36.8
15	51.6	54.4	48.2	31.5	45.1	65.2	38.0	43.2
22	50.4	53.9	48.1	35.5	41.7	61.9	40.2	39.2
29	62.1	55.6	44.3	33.4	45.8	68.1	42.3	40.0
37								
LSD(0.05)	12.9	NS	NS	6.4	7.8	NS	5.9	7.8
(0.10)	9.7	NS	4.7	5.2	6.4	4.8	4.7	6.4
CV(%)								

[2] 1987-88 locations

Table 5. Effect of P rate on N use efficiency for winter wheat grain in western Kansas in 1986-88.[+]

	Locations							
P Rate	Ford	Tregol	Kearny	Gove	Scott	Gray[2]	Trego2[2]	Greeley[2]
kg P/ha				%				
7	10.8	5.3	8.4	8.3	5.2	23.3	11.2	6.8
15	27.5	6.9	7.4	7.8	18.3	22.5	16.2	17.6
22	25.7	6.1	7.3	13.9	12.9	17.1	19.8	10.9
29	43.1	8.6	1.6	10.8	18.9	27.3	23.4	12.2
37								
LSD(0.05)	23.1	NS	NS	NS	NS	NS	NS	NS

$$+\quad \frac{\text{N uptake in P treatment} - \text{N uptake in check}}{\text{N rate}} \times 100$$

2 1987-88 locations.

Table 6. Effect of P rate on winter wheat grain P content in western Kansas in 1986-88.

	Locations							
P Rate	Ford	Tregol	Kearny	Gove	Scott	Gray[2]	Trego2[2]	Greeley[2]
kg P/ha	g/kg							
0	3.7	3.9	2.8	4.2	3.4	3.1	2.7	3.1
7	3.8	3.6	2.8	4.1	3.2	3.3	2.9	2.9
15	3.6	3.6	2.9	4.4	3.7	3.3	2.9	3.0
22	3.9	3.7	2.9	4.1	3.5	3.2	3.1	3.1
29	3.8	3.9	3.0	4.2	3.6	3.1	3.2	3.1
37	4.2	4.0	3.0	4.2	3.6	3.1	3.4	2.9
LSD(0.05)	0.3	NS	NS	NS	NS	NS	0.5	NS
(0.10)	0.2	0.4	NS	NS	0.4	NS	0.4	NS
CV(%)	5.3	7.6	12.5	4.4	9.3	6.4	8.4	5.7

2 1987-88 locations.

Table 7. Effect of P rate on winter wheat grain P uptake in western Kansas in 1986-88.

	Locations							
P Rate	Ford	Tregol	Kearny	Gove	Scott	Gray[2]	Trego2[2]	Greeley[2]
kg P/ha	----------	----------	----------	----------	kg/ha	----------	----------	----------
0	6.7	11.4	8.4	8.3	7.5	9.6	4.3	5.5
7	8.0	11.5	9.7	8.8	8.0	11.9	5.6	5.9
15	9.7	11.8	10.5	9.9	10.3	12.7	6.0	6.9
22	10.3	13.0	10.1	10.3	9.4	11.4	6.9	6.6
29	11.9	12.9	10.7	10.2	10.4	11.9	7.6	6.7
37	12.6	13.8	10.2	10.0	10.0	11.2	7.5	7.3
LSD(0.05)	3.0	NS	NS	NS	1.7	NS	1.3	1.3
(0.10)	2.1	NS	2.0	1.4	1.4	1.7	1.1	1.0
CV(%)	20	11.3	16.0	12.1	12.5	9.4	14.0	13.0

[2] 1987-88 locations.

Table 8. Effect of P rate on P use efficiency for winter wheat in western Kansas in 1986-88+.

P Rate	Ford	Tregol	Kearny	Gove	Scott	Gray[2]	Trego2[2]	Greeley[2]
	Locations							
kg P/ha				%				
7	18.8	0.8	17.7	6.3	6.8	32.4	18.5	5.6
15	20.7	2.7	13.8	10.8	18.8	20.3	11.0	9.1
22	16.4	7.1	7.7	8.7	8.6	8.1	11.5	4.9
29	17.9	5.0	7.8	6.5	9.9	7.9	11.2	4.0
37	16.1	6.7	4.9	4.6	6.8	4.4	8.4	4.8
LSD(0.05)	NS	NS	10.1	NS	7.3	8.2	NS	NS
(0.10)	NS	NS	8.5	NS	6.2	6.4	7.2	NS
CV(%)	8.2	9.2	9.9	8.3	9.8	10.5	7.9	13.2

$$+ \quad \frac{\text{P uptake (fertilized)} - \text{P uptake (check)}}{\text{P rate}} \times 100$$

2 1987-88 locations.

Table 9. Effect of P rate and placement on winter wheat grain yield in western Kansas in 1986-88.

	Locations				
	Ford	Kearny	Gray[2]	Greeley[2]	Trego[2]
	Mg/ha				
P Rate (kg P/ha)					
0	1.56	2.57	3.06	2.14	1.53
7	1.97	3.19	3.43	2.73	1.88
22	2.04	3.23	3.59	2.96	1.99
37	2.27	3.33	3.52	3.36	2.05
LSD(0.05)	0.28	0.32	0.44	0.37	0.28
CV(%)	15.3	4.00	9.0	7.5	15.6
Pr > F					
Rate	0.0001	0.0001	0.001	0.0003	0.009
+Chk vs fertilized	0.0001	0.0001	0.001	0.0001	0.0001
P Placement					
BC	1.83	3.01	3.40	2.62	1.64
KN	2.04	3.13	3.30	2.94	1.88
DR	1.97	3.18	3.48	2.81	2.00
SD	2.03	3.34	3.41	2.82	1.93
LSD(0.05)	0.22	0.14	NS	0.15	0.21
CV(%)	15.3	4.02	9.0	7.5	15.6
Pr > F					
Plac	0.068	0.08	0.21	0.001	0.008
+Bc vs banded	0.042	0.036	0.36	0.0003	0.001

[2] 1987-88 locations.
+ single df comparison.

Table 10. Effect of P rate on winter wheat grain yield in western Kansas (1984-85)

	Locations (co.)							
P rate	Ford	Wallace	Trego1	Trego2	Greeley	Karson	Sherman	Gray
kg P/ha	----------	----------	----------	---------- Mg/ha	----------	----------	----------	----------
0	1.83	2.93	3.69	2.98	3.22	1.57	5.10	1.25
7	1.90	3.62	3.47	3.17	3.48	2.08	4.75	1.31
15	2.19	3.81	3.55	3.27	3.55	2.08	4.71	1.39
22	2.42	3.71	3.36	3.27	3.29	2.36	5.06	1.52
29	2.37	3.87	3.29	3.32	3.54	2.29	3.99	1.40
37	2.55	3.93	3.38	3.41	3.57	2.33	4.09	1.42
P response?	Yes	Yes	No	Yes	No	Yes	No	No
Bray-1 P (mg/kg)	10.0	11.5	9.0	8.5	11.0	7.0	18.0	22.0

Table 11. Effect of P rate on winter wheat grain yield in western Kansas (1985-86)

	Locations					
P rate	Trego	Ellis	Sherman	Greeley	Gray	Grant
kg P/ha	Mg/ha					
0	1.19	1.28	1.44	1.82	2.73	3.15
7	1.47	2.04	1.81	2.34	3.05	3.19
15	1.58	2.20	2.03	2.28	2.74	3.38
22	1.68	2.27	2.11	2.47	2.56	3.34
29	1.52	2.02	2.18	2.39	2.75	3.29
37	1.69	2.21	2.08	2.42	2.56	3.14
P response?	Yes	Yes	Yes	Yes	Yes	No
Bray-1 P (mg/kg)	4.0	3.0	8.0	18.0	30.0	23.0

Table 12. Phosphorus recommendation for winter wheat as a Function of soil P test and sample depth.[+]

	P Recommendation (kg P/ha)					
Sample depth (cm)	37	29	22	15	7	0
	Bray-1					
15.0	<5	6-8	9-11	12-15	16-21	>22
22.5	<4	5-7	8-10	11-14	15-19	>20
30.0	<3	4-5	6-8	9-12	13-17	>18
	Olsen					
15.0	<4	5-6	7-8	9-10	11-13	>14
22.5	<4	5	6-7	8	9-10	>11
30.0	<4	5	6	7	8	>9
	Mehlich					
15.0	<5	6-9	10-12	13-16	17-23	>24
22.5	<4	5-7	8-10	11-13	14-19	>20
30.0	<4	5-7	8-9	10-11	12-16	>17

[+] Soil test values are in mg/kg

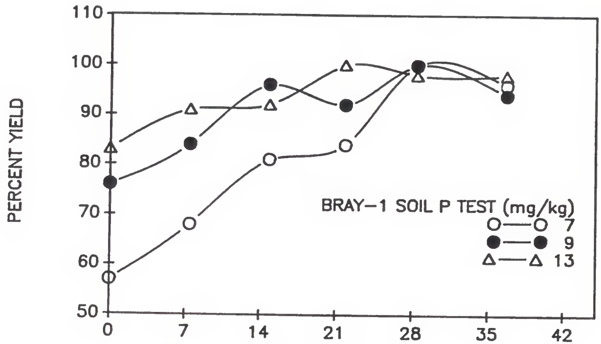

Figure 1. Yield response to fertilizer P as affected by soil P level.

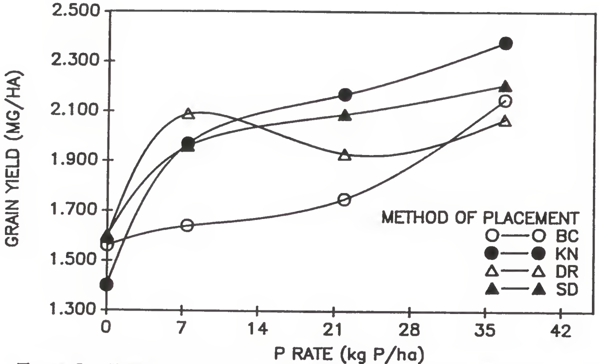

Figure 2a. Effect of P rate and placement on winter wheat grain yield. (Ford Co. 1986–87)

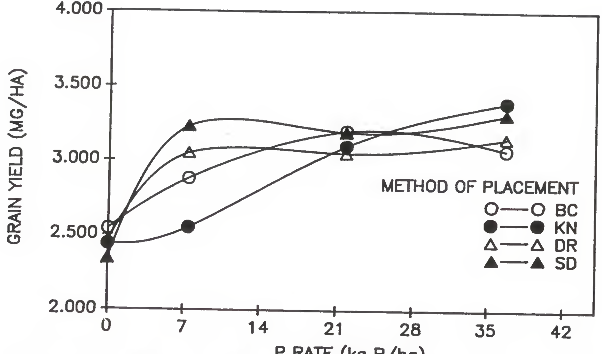

Figure 2b. Effect of P rate and placement on winter wheat grain yield. (Greeley Co. 1987–88)

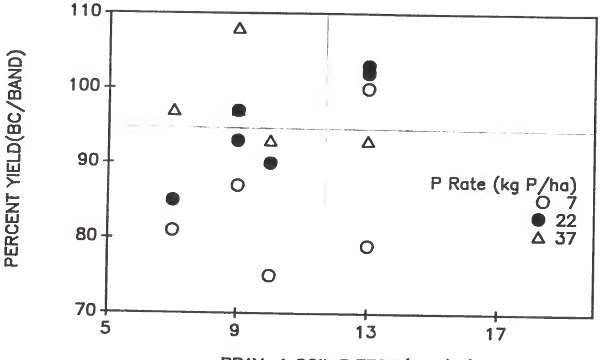

Figure 3. Winter wheat yield response as affected by P rate and placement.

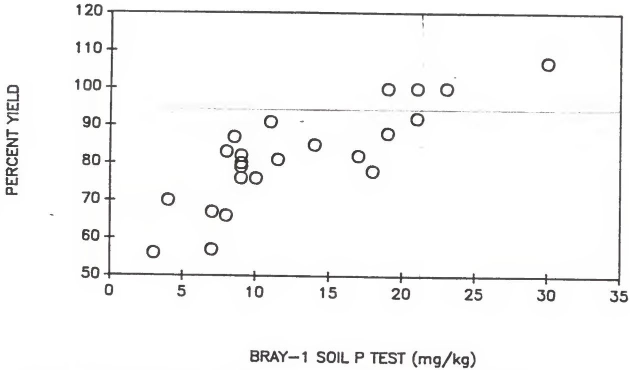

Figure 4. Winter wheat grain yield response as function of soil P test

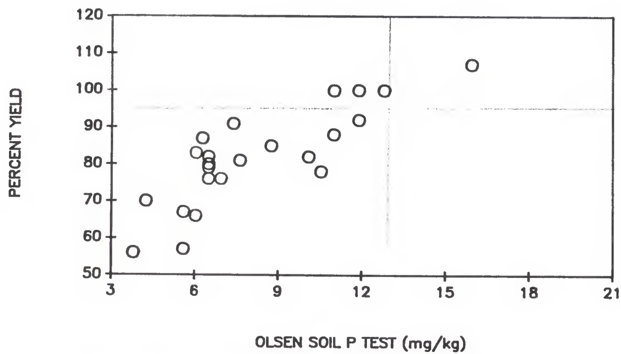

Figure 5. Winter wheat grain yield response as affected by soil P test.

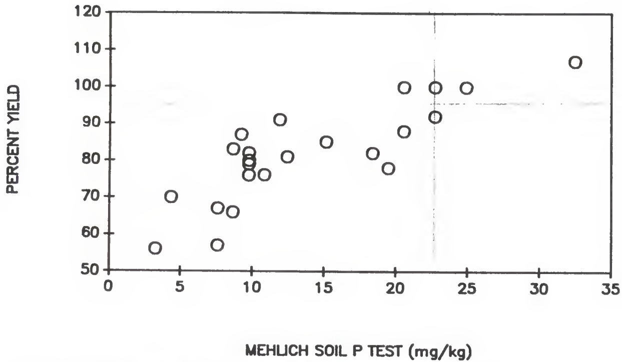

Figure 6. Winter wheat grain response as function of soil P test

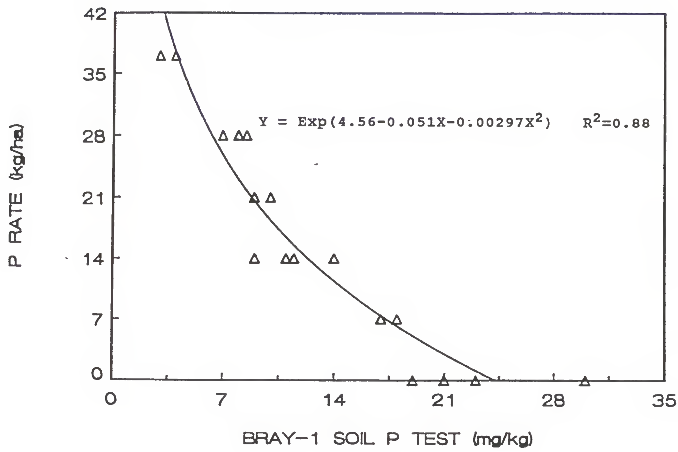

Figure 7. Bray-1 soil P test calibration for winter wheat (western Kansas 1985-88).

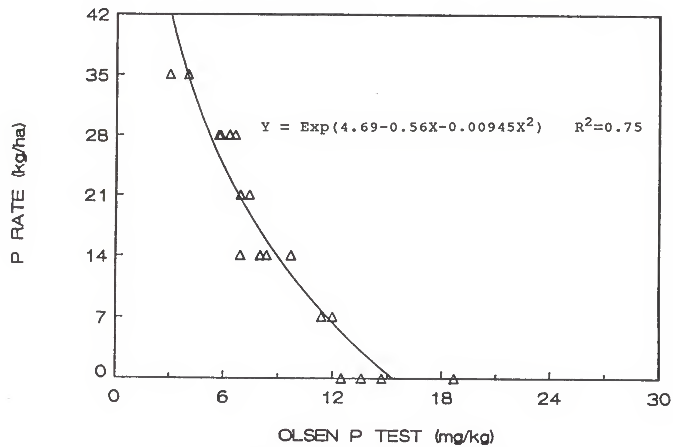

Figure 8. Olsen soil P test calibration for winter wheat (western Kansas 1985-88).

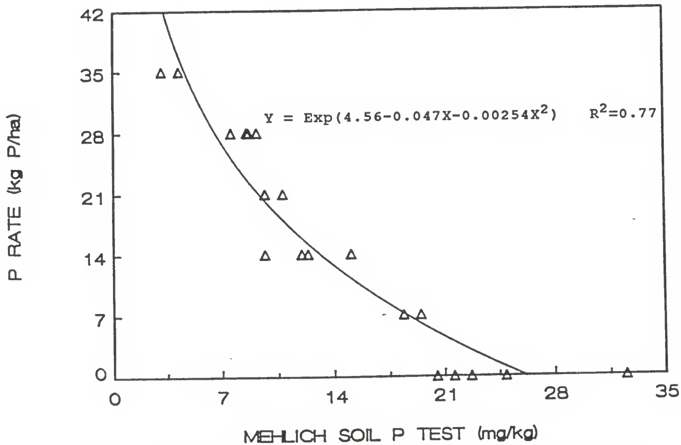

Figure 9. Mehlich soil P test calibration for winter wheat (western Kansas 1985-88).

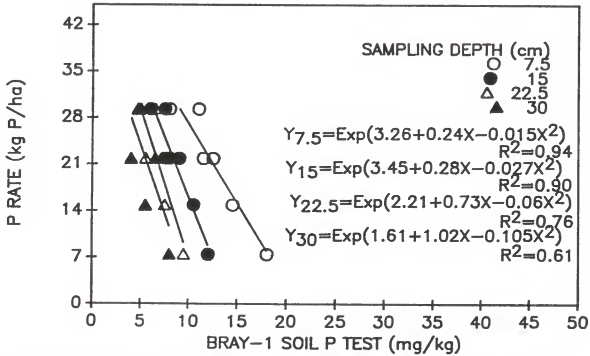

Figure 10. Bray−1 soil P test calibration as affected by sampling depth at 6 locations (see Table 2).

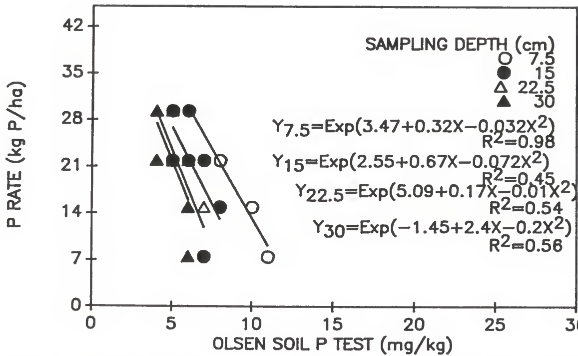

Figure 11. Olsen soil P test calibration as affected by sampling depth.

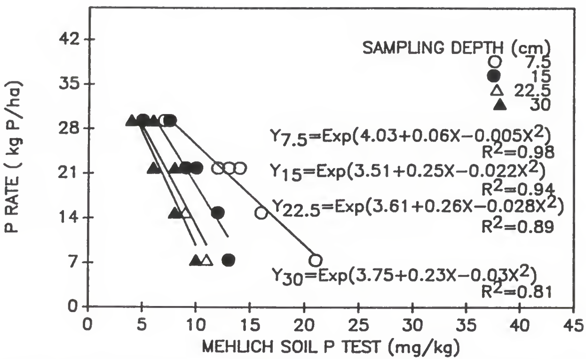

Figure 12. Mehlich soil P test calibration as affected by sampling depth.

Appendix Table 1. Phosphorus rate and placement effect on winter wheat grain yield in western

P rate	Placement			
	BC	KN	DR	SD
kg P/ha	------------------	Mg/ha	-----------------	
			Ford	
0	1.56	1.40	1.59	1.60
7	1.64	1.97	2.09	1.96
22	1.75	2.17	1.93	2.09
37	2.15	2.38	2.07	2.21
LSD(.05)	P rate 0.27		P placement	0.21
			Trego	
0	1.31	1.55	1.64	1.62
7	1.46	1.82	2.25	1.98
22	1.85	2.10	1.98	2.03
37	1.94	2.06	2.15	2.07
LSD(.05)	P rate 0.23		P placement	0.17
			Gray	
0	2.96	3.10	3.07	3.10
7	3.38	3.47	3.36	3.53
22	3.53	3.28	4.00	3.54
37	3.74	3.37	3.50	3.47
LSD(.05)	P rate 0.35		P placement	0.18
			Greeley	
0	2.54	2.44	2.46	2.34
7	2.88	2.55	3.05	3.23
15	3.20	3.10	3.05	3.19
22	3.07	3.40	3.15	3.31
LSD(.05)	P rate 0.30		P placement	0.14
			Kearny	
0	2.62	2.97	3.30	3.17
7	2.52	3.30	3.20	3.50
22	2.62	3.15	3.15	3.25
37	2.52	3.33	3.29	3.42
LSD(.05)	P rate 0.32		P placement	0.14

PHOSPHORUS MANAGEMENT OF DRYLAND WINTER WHEAT

(TRITICUM AESTIVUM L.)

IN WESTERN KANSAS

by

ALI DALY RADHOUANI

Ing.agro., INAT (Tunisia), 1982

AN ABSTRACT OF A THESIS

submited in partial fulfillment of the

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ABSTRACT

Dryland winter wheat is the most important crop in Kansas. Approximately 40% of the wheat acreage in Kansas testing low or medium low in available phosphorus (P),does not receive fertilizer P. This research was conducted in western Kansas to study the effect of P rate and placement methods on winter wheat grain yield. Studies were conducted at different locations throughout western Kansas in 1987 and 1988,representing a wide range in available soil P. Studies were done on Ulysses silt loam (aridic haplustoll),Harney silt loam (typic argiustoll),and Richfield silt loam (typic argiustoll) soils. In the rate studies six treatments (0, 7, 15, 22, 29, and 37 kg P/ha as ammonium polyphosphate,10-34-0) were evaluated in a randomized complete block design with four replications. In the placement studies four methods of placement were evaluated: broadcast (BC), knife (KN), dribbled over the row (DR),and seed placement (SD). Four P rates (0,7,22,and 37 kg P/ha) were applied with each placement method in a split-plot design with P rate and P placement as the main plots and subplots,respectively. Nitrogen (N) was balanced at 90 kg N/ha on all treatments. Results show that grain yield response was related to extractable soil P. Decreasing soil test P level resulted in higher probability of fertilizer P response and a higher P rate requirement for maximum yield. Bray-1 P test of 21 mg/kg was estab-

lished as the critical value, beyond which no P fertilizer response was expected. Corresponding values of 13 and 23 mg/kg were determined for Olsen and Mehlich P tests, respectively. Optimum fertilizer P rates of 37, 29, 22, 15, and 7 kg P/ha were calculated for <5, 6-8, 9-11, 12-15, and 16-21 mg/kg Bray-1 P, respectively. No P fertilizer response was obtained for soils exceeding 21 mg/kg Bray-1 P. Optimum P fertilizer rates also were established for the Olsen and Mehlich soil tests. Results showed that soil sampling depth greatly affected P recommendation. For the same optimum fertilizer rate, lower soil test P categories were needed as soil sampling depth increased. Results from the placement studies showed that banded P (KN,DR,and SD) performed equally and significantly better than broadcast P (BC). Results showed that with soils testing greater than 12 mg/kg Bray-1 P, broadcast P could be as effective as band applied P.